CityGML –
3D Geospatial and Semantic Modelling of Urban Structures

Prof. Dr. Thomas H. Kolbe

Institute for Geodesy and Geoinformation Science
Berlin University of Technology
kolbe@igg.tu-berlin.de

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Ongoing paradigm shift in spatial modelling:
- from geometry / graphics oriented models
- to representation of well-defined objects with their properties (among them spatial and graphical ones), structures, and interrelationships

Concerning 2D data: long tradition in European cadastres
- Germany: ALKIS/ATKIS/AFIS (AAA)
- UK: Ordnance Survey Mastermap
- Netherlands: Top10NL

Concerning 3D data: often seen as being identical with 3D graphics models of the respective region
- Google Earth [KML, COLLADA], X3D, 3D PDF, 3D Studio Max

However: numerous applications beyond 3D visualization
Applications of Virtual 3D City Models
3D City and Landscape Models

- are a product family on their own (like Building Information Models, BIM, are a product family)
- with specific applications (differing from BIM)

Characteristics

- complete representation of city topography / structures ‘as observed‘ (typically not ‘as planned‘)
  - often full spatial coverage of a city or district
  - built-up environment (buildings, infrastructure)
  - natural features (vegetation, water bodies, terrain)

- 3D geometry, topology, semantics, and appearance
- homogeneous data quality (at least on the same scale)
Information Modelling at Different Scales

Model content, structure, and employed modelling principles depend on:
- Scale
- Scope (application contexts)

Taken from the Homepage of the Helmholtz Research Center Karlsruhe, © Karl-Heinz-Häfele
CityGML – Modelling Urban Spaces

Application independent Geospatial Information Model for virtual 3D city and landscape models

- comprises different thematic areas
  (buildings, vegetation, water, terrain, traffic etc.)
- data model (UML) according to ISO 191xx standard family
- exchange format results from rule-based mapping of the UML diagrams to a GML3 application schema
- ongoing standardisation process in OGC

CityGML represents

- 3D geometry, 3D topology, semantics and appearance
- in 5 discrete scales (Levels of Detail, LOD)
CityGML Development

Originator: SIG 3D of the Initiative Geodata Infrastructure North-Rhine Westphalia in Germany GDI NRW

- more than 70 parties / institutions working on technical issues about virtual 3D city models
- T-Mobile, Bayer AG, Rheinmetall Defence, Environmental Agencies, Municipalities, UK Ordnance Survey, 11 Univ.

CityGML was brought into Open Geospatial Consortium for international standardisation by the end of 2004

- Handled by the 3D Information Modelling WG
- Current status: OGC Discussion Paper
- Roadmap: Best Practice Paper [July 2007], International Standard [December 2007]
Goals of CityGML (I)

Establish high degree of semantic (and syntactic) interoperability

- enabling multifunctional usage of 3D city models
- definition of a common information model (ontology)
- „3D geo base data“ (in the tradition of most European 2D digital landscape models, cadastre models)

Representation of 3D topography as observed

- explicit 3D shapes; mainly surfaces & volumes
- identification of most relevant feature types usable in a wide variety of applications
- limited inclusion of functional aspects in base model
Goals of CityGML (II)

Suitability for **Spatial Data Infrastructures**
- mapping to appropriate exchange format -> **GML3**
  - needs high degree of expressivity wrt. OO models
  - must be usable in the context of OGC Web Services
- possibility to **link any CityGML feature** to more specialised, functional models / external data sources

Must be **simple to use** for applications
- **well-defined semantics** for feature types; however semantic structure not too fine-grained
- subset of GML3 geometries (no curved lines, surfaces)
  - **Boundary representation** with absolute coordinates
  - advantage: **directly manageable** within 3D GIS / geo DB
Multi-scale modelling: 5 levels of details

- LOD 0 – Regional model
  - 2.5D Digital Terrain Model
- LOD 1 – City / Site model
  - “block model“ w/o roof structures
- LOD 2 – City / Site model
  - textured, differenciated roof structures
- LOD 3 – City / Site model
  - detailed architecture model
- LOD 4 – Interior model
  - “walkable“ architecture models
## Thematic Modelling in CityGML

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**<<FeatureCollection>>**
- CityModel

**<<Feature>>**
- _CityObject

**ExternalReference**
- informationSystem: anyURI
- externalReference: ExternalObjectReferenceType

- _Transportation Objects
- _City Furniture
- CityObject Group
- _Water Bodies
- _Site
- _Vegetation

- Complex Relief

- IoD1GeometryProperty
- IoD2GeometryProperty
- IoD3GeometryProperty

- Geometry
DTM for each Level of Detail can be composed of

- **TINs** (Triangulated Irregular Network), **Grids**, **3D Breaklines**, and **3D Mass Points**

- Each DTM component may be restricted to be valid in a specific region by providing a **validity extent polygon**

Validity extent polygon can have holes which allow nested DTMs!
Building Model

- Coherent aggregation of spatial and semantical components
  - (recursive) composition of building parts
  - thematic surfaces (roof surface, wall surface, etc.) [from LOD2]
  - building installations like dormers, stairs, balconies [from LOD2]
  - openings like doors and windows [from LOD3]
  - rooms and furniture [in LOD4]

- Components contain relevant thematic attributes
  - name, class, function, usage, (constr. date, roof type, address)
  - no. of storeys above / below ground, storey heights

- Surface appearance characteristics (textures, colours)
Spatio-semantical Composition

3D-Modell: Stadt Coburg

Building

BuildingPart

BuildingPart

BuildingInstallation (Dormer)

Building surface (WallSurface)
Coherent Building Model in Level of Detail 3

3D-Modell: Dr. Benner, Forschungszentrum Karlsruhe
Further CityGML Concepts

- Support for **generalization of 3D data**
  - Generalized objects are linked to the original objects on the larger scale

- **Explicit linking**
  - Every CityGML object can have an arbitrary number of links to external resources (files, objects, database entries)

- **Object history**
  - Objects may have a lifespan (incl. termination date)

- Support for spatial homogenization / integration
  - e.g. **Terrain Intersection Curves** (for integration of 3D objects with the terrain)
Terrain Intersection Curve (TIC)

„Interface between 3D objects and the terrain“

- ensure matching of object textures with the DTM
- DTM may be locally warped to fit the TIC
Closure Surfaces

„Seal open 3D objects“

- in order to be able to compute their volumes
3D Information Communities

Extending CityGML for specific application domains
Application Specific Extensions to CityGML

- CityGML should be considered a **base information model** for virtual 3D city models

  - **But:** Specific applications need specific extra information
    - typically in close interaction with CityGML base information

- **Examples**
  - **Environmental simulations** like noise immission mapping need information about noise absorption of surfaces
  - **Cultural heritage** needs to augment objects by their heritage and history, and has to consider the development along time
  - **Utility networks** need to represent pipes, pipe tunnels, connectors, transforming devices
Application Domain Extensions (ADE)

NoiseSimul.  
Disaster management

CityGML

AAA / NAS

GML

XML
Application Domain Extensions (ADE)

Types of domain specific extensions:

- Extension of existing CityGML feature types by
  - additional spatial and non-spatial attributes
  - additional relations / associations

- Definition of new feature types
  - preferably based on CityGML abstract base class CityObject

General considerations:

- minimal invasive wrt. current CityGML structure
- for each geometry attribute the LOD has to be indicated in the element name, e.g. lod2MultiCurve or lod3Surface
  - multiple LODs: similar realization as CityGML core feature types
**Example** for a CityGML Building feature with application specific **extra information** (qualified by a namespace):

```xml
<Building>
  <function>1000</function>
  ............
  <noise:NoiseReflection>12</noise:BuildingReflection>
  <noise:BuildingHabitants>8</noise:BuildingHabitants>
  .................
  <lod2Solid> ...... </lod2Solid>
</Building>
```
Besides the OGC Testbed OWS-4, CityGML is applied in an ongoing project in Germany:

▸ Computation of the **noise immission maps** in the state North Rhine-Westphalia (18 million citizens)

▸ **Background: Environmental Noise Directive** from the European Commission

▸ System Architecture (using the GDI NRW), Web Services: WFS, WMS; Data formats: ATKIS, CityGML

▸ **Estimated savings** (wrt. proprietary systems): >10 Mio €

▸ Extension of CityGML by noise relevant attributes and features: **CityGML Noise ADE**
Noise Immission Mapping

3D block model in CityGML from WFS-T

DTM 10m grid in GeoTiff from WCS

noise immission simulation

noise immission maps for European Union reporting (using WMS)
(Some) CityGML Implementation Issues
(City)GML files become very large (several GB for bigger municipalities)

- file sizes can be effectively reduced by gzip compression
- but: XML validation and processing can be problematic (classical DOM parsing not feasible due to main memory limitations)
- WFS access might have to be realized in an asynchronous way in order to avoid timeouts

Complex data model

- extensive use of OO modeling -> puts considerable demands on the modelling power of processing and storage components
- Aggregation hierarchies: nested objects
- Specialization hierarchies: inheritance of object properties
XLinks
- Complex objects can be represented inline, in a self-contained way
- But: sub-objects may be also distributed over different files (even Web Services) and only referenced by their parent objects
- GML object referencing employs the XLink standard of the W3C

Topology
- topological relations are realized by reusing (partial) geometries;
- reusage: referencing the same geometry from different objects
- referencing uses XLinks, referenced geometries need to have IDs

Geometry Model
- See next slide
3D GML geometries are represented as B-Rep with absolute (world) coordinates (but always with CRS!)
- no scene graph concepts like transformation nodes
- the CRS is (one) key to the integration of different spatial datasets

No generative modeling principles like CSG, Sweep Repr.
- Very few implicit (parametric) shape definitions (e.g. Box, TIN)

Reusability of geometry within a dataset is limited
- However useful to express topological connectivity of different features or semantic relations between them

Advantages of the GML3 geometry model
- easy to spatially index and manage within spatial databases and GIS; native support by Oracle, PostGIS, MySQL etc.
- visualization (transformation to X3D) is immediate
CityGML from the BIM perspective

- Provision of **information about the surroundings** / environment of buildings and sites
  - **Embedding of 3D models** into the real world’s coordinate frame
  - Analysis and **identification of suitable locations** for construction
  - Querying 3D urban objects with **geospatial selection criteria**
  - Useful for planners, architects, and engineers

- Can be a source format for the creation of Building Information Models from observed data
  - for example CityGML -> IFC
  - CityGML objects already carry semantic information which are helpful in interpretation processes
  - CityGML especially suited for the stepwise reconstruction and refinement of urban objects (coping with different model qualities)
BIM from the CityGML perspective

- Behind IFC there is also a *semantically rich information model*
  - In fact, it is more detailed than CityGML
  - However, **lack of other city features**; limited georeferencing

- **Source for highly detailed building model data**
  - with respect to geometry and semantics
  - can be used to provide LOD3 and LOD4 models

- CityGML building model adopted some of the conceptual modelings of IFC
  - IFC spaces -> CityGML rooms
  - IFC Property Sets -> CityGML generic attributes, now also ADEs
3D visualization from the CityGML perspective

- **3D visualization** is the **result of a portrayaling process** applied to a CityGML model
  - CityGML is a source structure for visualization processes; not intended to be used as a 3D graphics format

- **Portrayaling**
  - **simplest form**: 1:1 **conversion** of geometry and appearance data to a 3D graphics format (incl. coordinate transformations)
  - **more sophisticated**: 3D **cartographic design**, for example:
    - Text and label placement
    - Symbolization and non-photo realistic rendering
    - Generalization

- **Appropriate OGC Web Services for 3D portrayaling**: Web 3D Service and Web Terrain Service
3D visualization from the CityGML perspective

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Appropriate OGC Web Services for 3D portrayaling:
- Web 3D Service
- Web Terrain Service

Non-photo realistic rendering. © J. Döllner & M. Walter, 2003
The Official 3D City Model of Berlin

3D visualization is the result of a portrayaling of Berlin‘s 3D city model (modeled according to CityGML)

www.3d-stadtmodell-berlin.de
Coming to the end...
CityGML is a

- **Geospatial Information Model** (based on ISO 191xx)
- and **Exchange Format** for virtual 3D city and regional models (realised as GML3 Application Schema)

CityGML represents **Geometry, Topology, Semantics, and Appearance**

- esp. semantic / structural information is needed for a range of applications

Should be considered as a **rich 3D information** source for the **generation of** (also cartographic) **3D visualizations**

- WFS [CityGML] -> W3DS [X3D and KML / COLLADA]